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Extended abstract

The Great Australian Bight – from AVO prospectivity screening to potentially drillable targets in one of the world's remaining untapped basins

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Abstract. The Ceduna Sub-basin in Australia's southern margin offers an untapped opportunity for significant petroleum resource as part of the global exploration portfolio. Analogous to the prolific Niger delta in both size and structural style, this highly-extensional province contains up to 15 km of largely untested post-rift sediments including two widespread Late Cretaceous deltas linked to world-class oil-prone marine Cretaceous source rocks.

Regional interpretation of legacy 2D seismic across the Bight Basin brings the sheer scale and structural complexity of this giant Cretaceous depocentre into perspective, but it is only through the detailed analysis of 8001 km^2 of dual-sensor towed streamer 3D seismic that its true potential can be quantified. Rigorous phase and amplitude AVO QC of the pre-stack information, coupled with optimised velocity models fed into the depth migration sequence, have ensured amplitude fidelity and phase stability across all offset ranges. This has enabled a systematic and robust exploration workflow of AVO analysis and pre-stack inversion despite limited well data. Numerous dual-sensor case studies have nevertheless demonstrated these Relative Acoustic Impedance and Vp/Vs volumes to be reliably robust for prospect de-risking because of the extended low frequency bandwidth.

Frontier screening supported by a partially-automated high-resolution stratigraphic framework has led to the identification of numerous prospects at multiple stratigraphic levels across the survey area. This includes isolation of laterally extensive and vertically amalgamated fan-like structures within the shallow Hammerhead delta using horizon-constrained high-definition spectral decomposition, and the extraction of potential AVO anomalies within the deeper structurally-controlled White Pointer sands draped across large gravity-driven listric growth faults.

Keywords: Ceduna, MC3D, multiclient, Springboard, PGS.

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Introduction

The offshore Ceduna Sub-basin in Australia's southern margin offers an untapped opportunity for significant petroleum resource as part of the global exploration portfolio. Analogous to the prolific Niger delta in both size and structural style, this highly-extensional province contains up to 15 km of largely untested post-rift sediments.

Prospectivity in the region is focused around two considerable Late Cretaceous deltaic supersequences, which have been classified by Totterdell *et al.* (2000) as two separate depositional systems: the marginal marine Cenomanian White Pointer delta and the overlying and strongly progradational Campanian to Maastrichtian Hammerhead delta. These systems are separated by the Turonian to Santonian marine shales of the Tiger supersequence, which is also considered to be a world-class oil-prone source rock interval. The organic-rich shales of the Tiger Formation are believed to have generated light oils with expulsion during the Campanian to recent over most of the basin (Struckmeyer *et al.* 2001).

We discuss the rapid geological and geophysical screening interpretation of the 8001 km^2 Springboard MC3D GeoStreamer® seismic survey acquired by PGS MultiClient in 2015. A high-fidelity pre-stack broadband image was constructed using the dual-sensor recordings to facilitate both structural interpretation and qualitative AVO analysis. Results from this integrated study are used to demonstrate exciting prospectivity potential in a truly frontier exploration province.

Basin overview, key challenges and target stratigraphy

Located in the underexplored pocket of Australia's southern margin, the Bight Basin comprises four main depocentres: the Ceduna, Duntroon, Eyre and Recherche sub-basins. Our study area is focused in the highly-extensional Ceduna Sub-basin, the largest of the four depocentres, which contains a Middle Jurassic to Late Cretaceous sedimentary succession (fluvial to paralic sediments) greater than 15 km thick. The presence of thick deltaic units and indications of active petroleum systems (i.e. Jerboa-1 paleo-oil column in the adjacent Eyre Sub-basin) enhance the potential prospectivity of one of the largest and least explored passive margins in the world (adapted from Totterdell and Krassay 2003).

The basic regional framework of the Ceduna Sub-basin is well understood based on interpretation of densely spaced, fair to moderate quality 2D seismic acquired since the mid 1960s. Industry interpretation of each subsequent vintage has improved the understanding of basin mechanics and has provided excellent insight into the dominant play types in the region. Proposed post-rift plays include stratigraphic targets within the shallow Hammerhead delta and structural targets within the deeper White Pointer sands draped across large gravity-driven listric normal growth faults. 2D seismic imaging of Jurassic syn-rift strata below the regional Blue Whale Albian detachment has historically been poor and highlights the important role of 3D seismic acquisition to unlock future exploration potential.

Another common frontier challenge is the paucity of deep water wells, and only two wells (Potoroo-1 and Gnarlyknots-1A) have been drilled in the Ceduna Sub-basin to date; Gnarlyknots-1A (2003), drilled in 1316 m of water, is the only true deep water test of the basin. However, it failed to reach its primary Cenomanian (White Pointer) objective and was suspended due to bad weather conditions. Neither well acquired shear-wave logs to enable forward modelling of AVO responses, and so the basin remains uncalibrated from a Quantitative Interpretation (QI) perspective.

The historical absence of 3D seismic data has also hampered the ability to fully assess the basin's true prospectivity potential, a key objective of this study and only made possible by recent acquisition. We focus on rapid geological and geophysical screening interpretation of the 2015 Springboard MC3D dual-sensor streamer seismic survey.

Prospectivity screening workflow in a frontier basin

The primary aim of this screening study was to demonstrate that efficient and robust characterisation of a frontier basin could be systematically achieved with high-resolution 3D seismic. The workflow was divided into three main parts: (1) Build structural and stratigraphic framework from the PSTM full-stack volume using the Geoscience Australia supersequence scheme tied to wells using 2D seismic tie lines, (2) Perform rigorous AVO QC of pre-stack gathers to produce AVO-compliant partial angle stacks, and (3) Integrate all of the above to generate uncalibrated Relative Acoustic Impedance (AI) and Vp/Vs products for QI-based prospectivity screening.

Structural interpretation

Faults were mapped in time throughout the 8001 km^2 survey area, from the Jurassic syn-rift to the Cretaceous post-rift sedimentary sections. Different structural styles were observed, with a clear difference in the orientation of the west–east normal faults between the Jurassic (Tithonian) system associated with the initial extension of the syn-rift period (deeper faults), and those of the Cretaceous (Cenomanian) gravity-driven listric growth normal faults, which detach downwards into the underlying mobile shales of the Blue Whale supersequence. The listric faults controlling this compartmentalised Cretaceous depocentre do not appear to breach the regional detachment separating the underlying Jurassic sediments; however, multiple detachments have been interpreted at this level, which appear to coalesce at depth to the southwest. These large-scale Cretaceous normal faults are the dominant structural mechanism in the study area, and prospective structural plays have been identified within the associated White Pointer petroleum system.

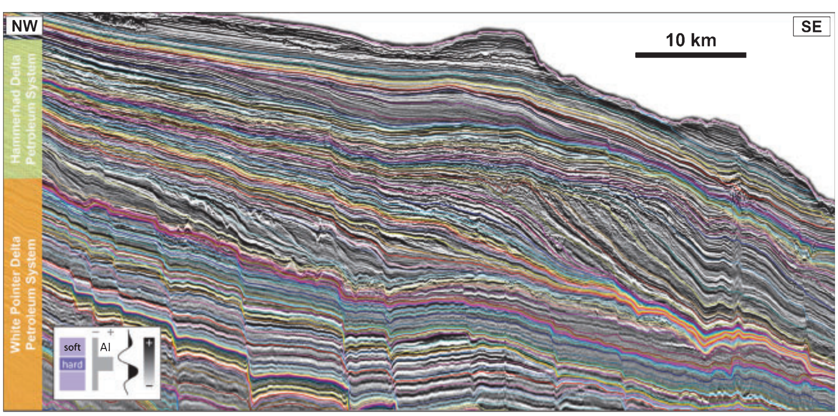

Fig. 1. Partially-automated stratigraphic framework built from the Springboard MC3D Full-Stack PSDM Volume.

Stratigraphic interpretation

The main tectono-stratigraphic framework for the Springboard area was based on the supersequences devised by Geoscience Australia (Totterdell *et al.* 2000). Seven partially-automated horizons (Fig. 1) were interpreted to constrain the Cretaceous post-rift interval: Seafloor/Top Dugong, Base Dugong/Top Wobbegong, Top Hammerhead, Base Hammerhead, Intra-Tiger, Top White Pointer and Top Bronze Whaler.

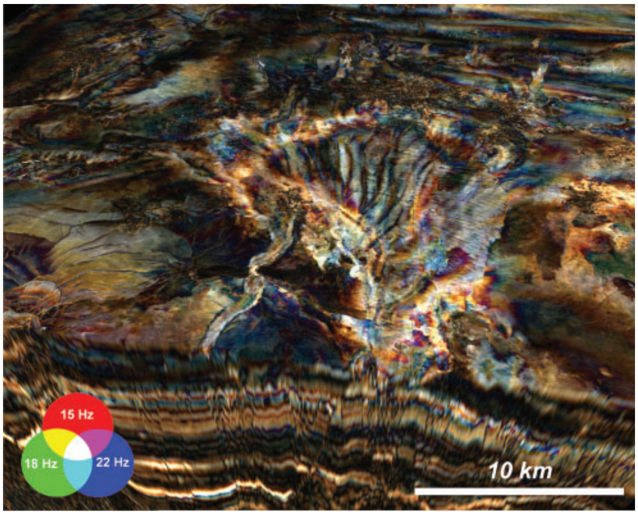

Fig. 2. Spectral decomposition and RGB frequency blending extraction showing the potential early formation of two overlapping fan-like structures within the Hammerhead petroleum system identified using the stratal slicing method.

Prospectivity screening using stratal slicing and spectral decomposition

The stratal slicing technique was used to map depositional systems with high resolution across the Springboard MC3D area. Application of this technique to the Hammerhead interval (even at a screening level) allowed us to trace the evolution of the delta. This also facilitated the identification of potentially prospective and amalgamated fan-like structures via deep canyon systems within this deltaic supersequence, and highlights the potential for large-scale plays within the Ceduna Sub-basin. Spectral decomposition and frequency blending were also applied to further delineate their areal extent (Fig. 2).

AVO prospectivity screening

Rigorous phase and amplitude AVO QC of the Springboard MC3D pre-stack information, coupled with optimised velocity models fed into the migration sequence, have ensured amplitude fidelity and phase stability across all offset ranges. This has enabled a systematic and robust exploration workflow of AVO analysis and pre-stack inversion despite limited well data. Numerous dual-sensor case studies have demonstrated these Relative AI and Vp/Vs volumes to be reliably robust for prospect de-risking (in the absence of wells) as a result of the extended low frequency bandwidth.

The processing team worked closely in cooperation with reservoir geoscientists to ensure uncompromised AVO

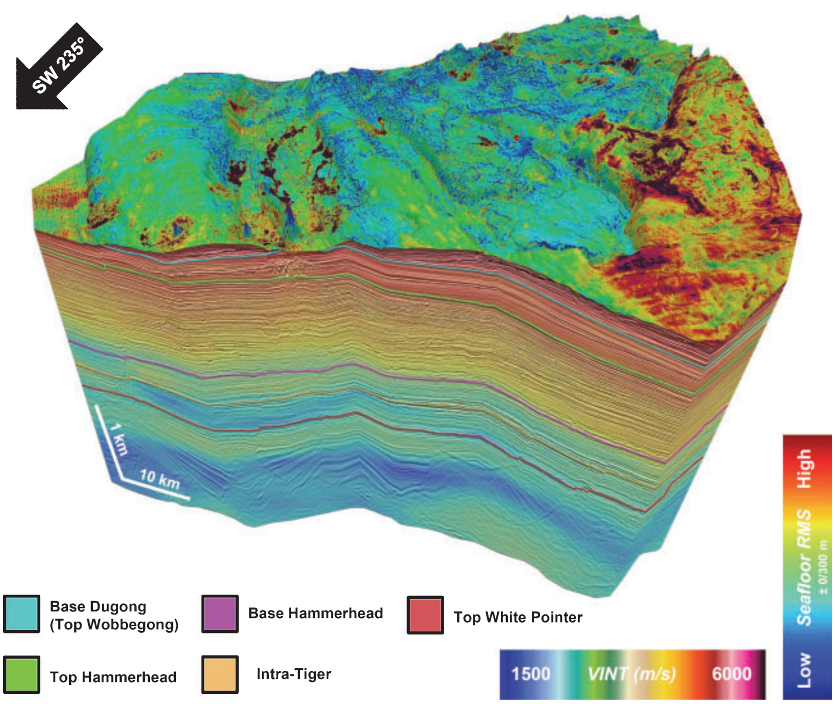

Fig. 3. 3D rendering of the Springboard PSDM horizon-constrained tomographic interval velocity model with an RMS extraction of the highly-rugose Ceduna seafloor.

preservation/enhancement. Systematic checks were performed on the pre-stack gathers to ensure that they were appropriately conditioned for AVO attributes extraction. Examples of global checks included detailed velocity analysis to ensure gather flatness at all target levels, selection of correct mutes to determine suitable partial stack angle ranges to comply with the two-term linearised Shuey approximation, multi-window and horizon-based spectra extractions to check spectral balancing between partial angle stacks, and goodness-of-fit to evaluate conformance of the pre-stack gathers to Shuey's two-term model. Each QC step was performed using both seismic sections and intercept-gradient cross-plots after specific processing milestones to manage the progressive improvement of results. This included passes of Radon Demultiple, Trim Statics and various forms of de-noise.

Several AVO-screening volumes were produced to high-grade anomalous areas within the Springboard survey because of the uncalibrated nature of the basin. Geobody extraction tools were then used to isolate the strongest anomalies for further interpretation.

Results have allowed the diagnosis of sizeable potential leads, which are often characterised by 3-way dip-closed structures with stacked reservoir objectives and a structurally conformable AVO amplitude anomaly.

The importance of depth imaging in a complex geological setting

The dual-sensor Springboard MC3D and conventional Ceduna 3D seismic have been processed as a seamless 20 000 km^2 PSDM volume to become the largest depth imaging product anywhere in the basin. The impact of the depth migration sequence on both the Ceduna subsurface image and structural prospect validity (especially within the White Pointer supersequence) is significant to developing a credible trap story.

Numerous geologic factors posed challenges to the velocity model build and were addressed over six iterations (Fig. 3). These include the highly-rugose seafloor, laterally changing velocities within the Tertiary overburden, laterally and vertically amalgamated pockets of shallow potentially high-velocity channels, strongly progradational deltaic shallow marine sandstones, Eocene volcanics, highly-rotated listric growth faults and overpressured shales at the approximate Albian detachment level, which form shale diapirs and produce a basal velocity inversion.

The Springboard PSDM results provide additional information on the structural model, and more specifically, on the nature of faults within the Cretaceous to Tertiary post-rift sedimentary layers. The geometry of listric normal faults above the Albian detachment level is also better resolved after the depth migration. Positioning and focusing of deep linear Jurassic syn-rift faults and basement morphology has also experienced a significant uplift.

Summary and conclusions

The new high quality regional PSTM and PSDM products demonstrate that there are numerous potential leads of large scale supported by AVO anomalies throughout the Springboard area and highlights the importance of accurate depth imaging to verify structural closure and improve well placement. Whilst yet unproven, the Ceduna Sub-basin remains of high interest and has the potential for world-class discoveries.

Conflicts of interest

The authors have no conflicts with any organisation or people.

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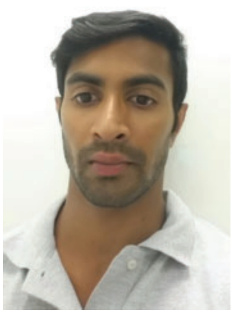

Dushyan Rajeswaran holds a BSc Honours (2008) from Curtin University, Western Australia, in the field of Geophysics. His first technical role was with ExxonMobil (2009) working for six years as an exploration geoscientist in several projects covering Asia-Pacific. He has since joined PGS (2014) and is currently in the position as Senior Geoscientist and Team Leader for the Reservoir organisation in Perth. Current industry memberships include PESA and SEAPEX.

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